Interannual to Decadal Variability of Ocean Evaporation as Viewed from Climate Reanalyses

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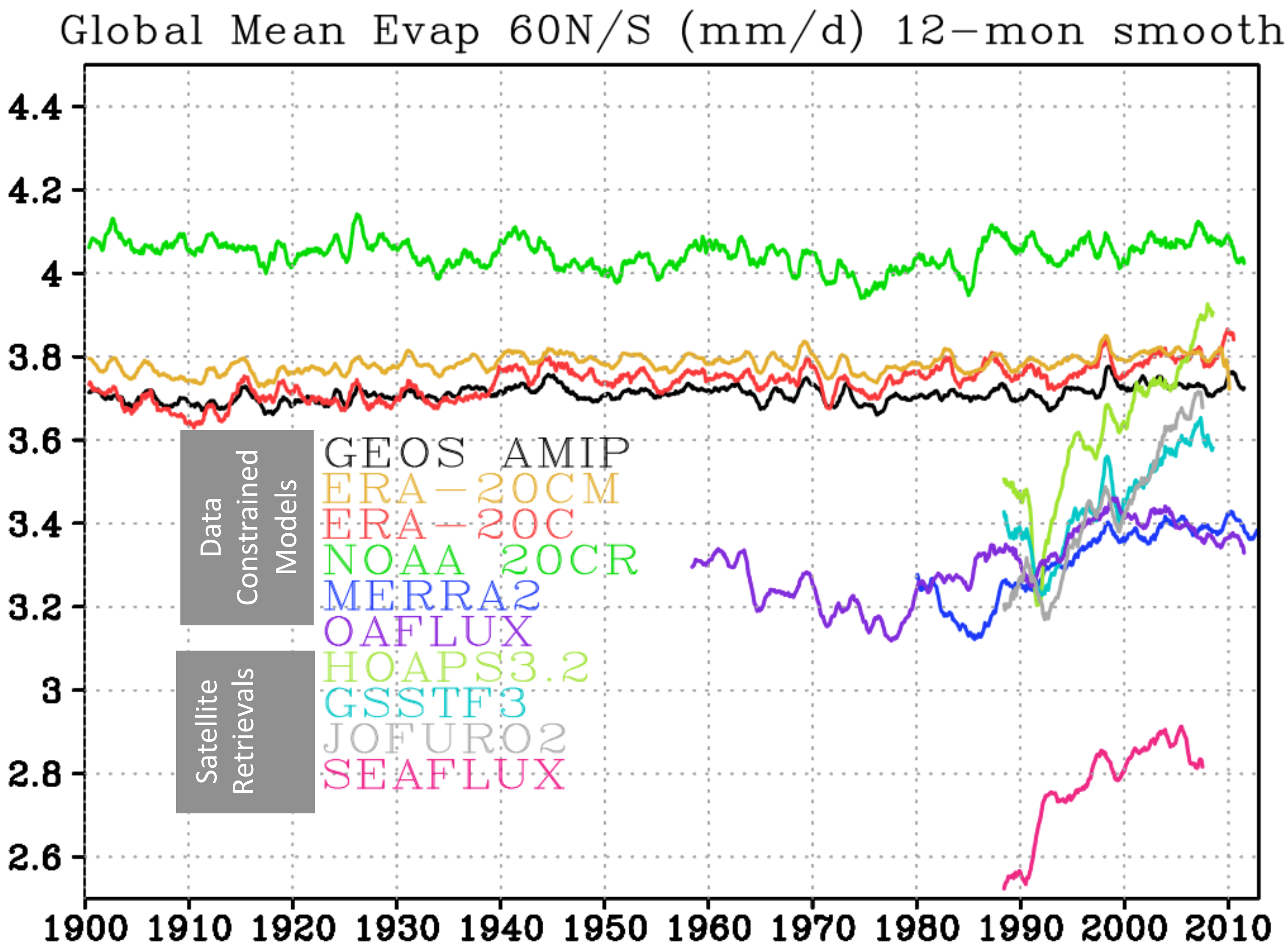
Substantial Disparities Exist in Global Ocean Evaporation Estimates



A Hierarchy of Global Ocean LHF Estimates

←More Observ Constrained

AGCMs w/ Specified SSTs (AMIPs) GEOS-5, ERA-20CM Ensembles

Incorporate best historical estimates of SST, sea ice, radiative forcing

Atmospheric "weather noise" is inconsistent with specified SST so sfc fluxes can be wrong sign (e.g. Indian Ocean Monsoon, high latitude oceans). Averaging over ensemble members helps isolate SST-forced signal.

Reduced Observational Reanalyses: NOAA 20CR V2C, ERA-20C

Incorporate observed Sfc Press (20CR) and Marine Winds (ERA-20C) to recover much of the evaporation induced by true synoptic or weather "noise"

Comprehensive Reanalyses (MERRA-2)

Full suite of observational constraints- both conventional and remote sensing. But… substantial uncertanties owing to evolving satellite observing system.

Multi-source Statistically Blended OAFlux, LargeYeager

Blend reanalysis, satellite, and ocean buoy information. While climatological biases are removed, non-physical trends or variations in components remain.

"Observations"

Satellite Retrievals GSSTF3, SeaFlux, HOAPS3…

Global coverage. Retrieved near sfc wind speed, & humidity used with SST to drive accurate bulk aerodynamic flux estimates. Satellite inter-calibration, spacecraft pointing variations crucial. Short record (1987-present).

In situ Measurements ICOADS, IVAD, Res Cruises

VOS and buoys offer direct measurements. Sparse data coverage (esp south of 30S. Changes in measurement techniques (e.g. shipboard anemometer height).

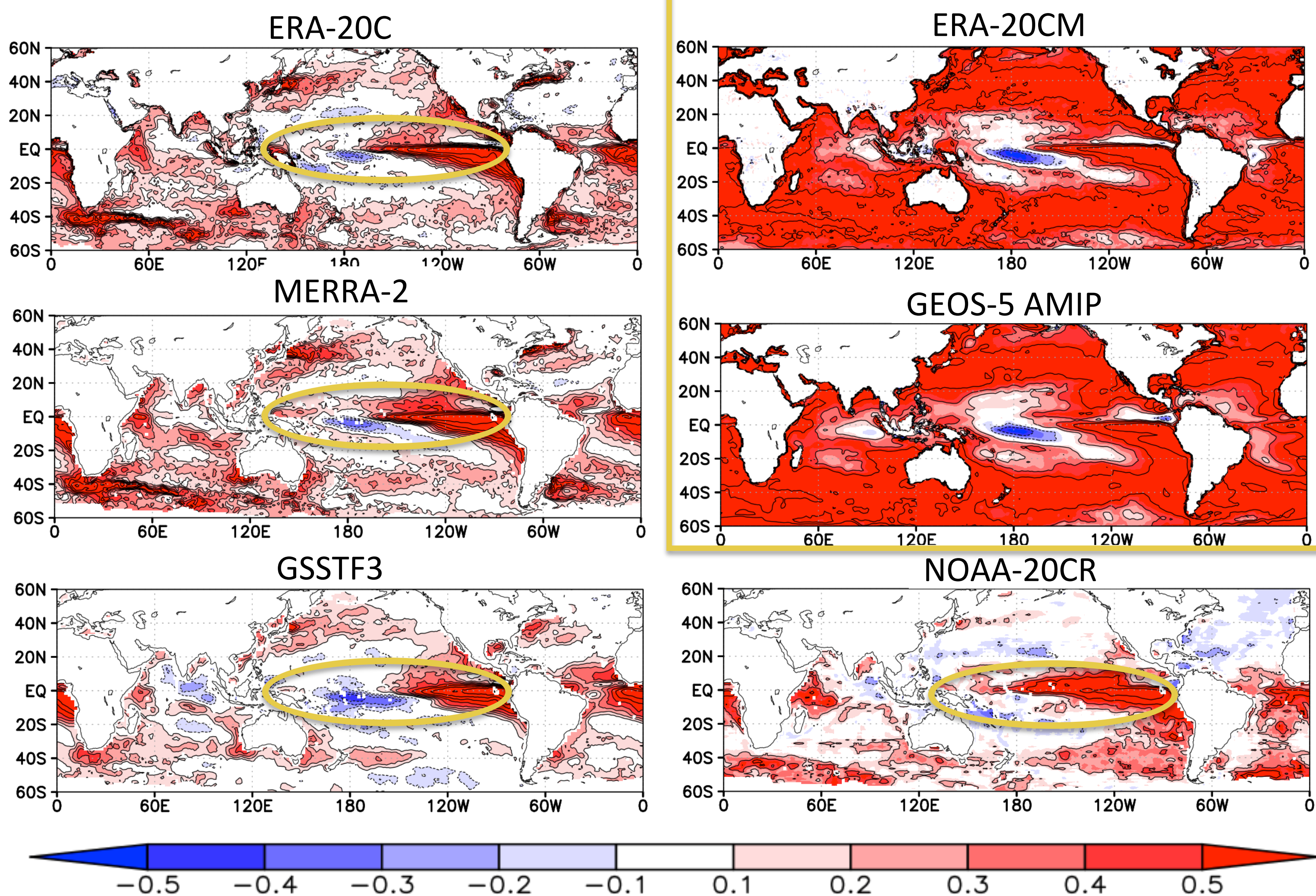
Questions we'll address

- Given the uncoupled framework of "AMIP" experiments, what can they tell us regarding evaporation variability?
- Do Reduced Observations Reanalyses (RedObs) using sfc pressure (and wind) provide a more realistic picture of evaporation variability?
- What signals of interannual variability (e.g. ENSO) and decadal variability (IPO) are detectable with this hierarchy of evaporation estimates?

SST variability forcing of evap is limited to key regions

Local Correlation (SST, Evap)

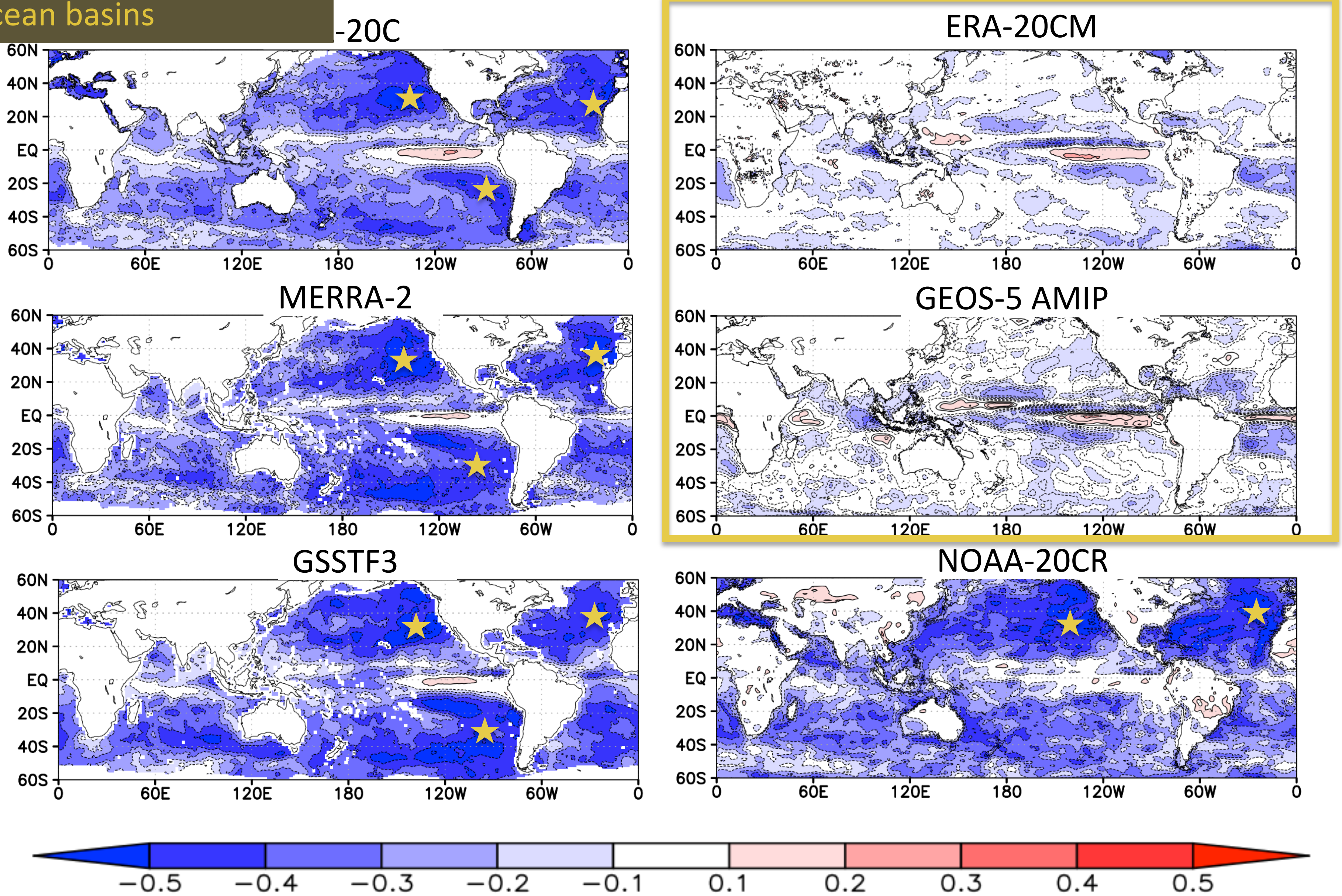
AMIP tightly couples evap to SST forcing



Local Correlation (SST_t, Evap)

Strongest evap forcing of SST resides in extra-tropical eastern ocean basins

Correct extra-tropical SST forcing by evap is missing in AMIPs



What's the Interpretation?

As with previous studies (e.g. Barsugli & Battisti,1999; Wu et al, 2006; Chen et al, 2013; 2014) specifying AGCM boundary forcing (i.e. SST) yields evaporation ("atmospheric noise") inconsistent with the SST forcing.

- Atmospheric "weather noise" differs *deterministically* from that which originally helped force the observed SSTs (even though it is *stochastically* similar).
- The problem is most pronounced at mid- to high latitudes and in association with the Monsoon regions.

By ensemble averaging (Chen et al; 2013; 2014) we expect that evaporation associated with internal atmospheric variability is greatly reduced, leaving the SST forced signal.

A Taylor Series Expansion of Bulk Aerodynamic Evaporation Around Monthly Climatology

As in Richter and Xie (2008), Lorenz et al (2010) we first write the bulk formula for evaporation as a function of SST, Relative Humidity, Wind Speed, and Stability:

near-sfc q_a

$$E = C_E \rho_a U q_o \left[q_s(SST) - RH \cdot q_s(SST + S) \right]$$

where we use the analytical expression for saturation specific humidity

$$q_s(SST) = q_o e^{\beta(SST)}, \; \beta = e^{(a - b/SST - c \ln(SST))}, \quad S = T_{air} - SST$$

and q_o, a, b, c are constants.

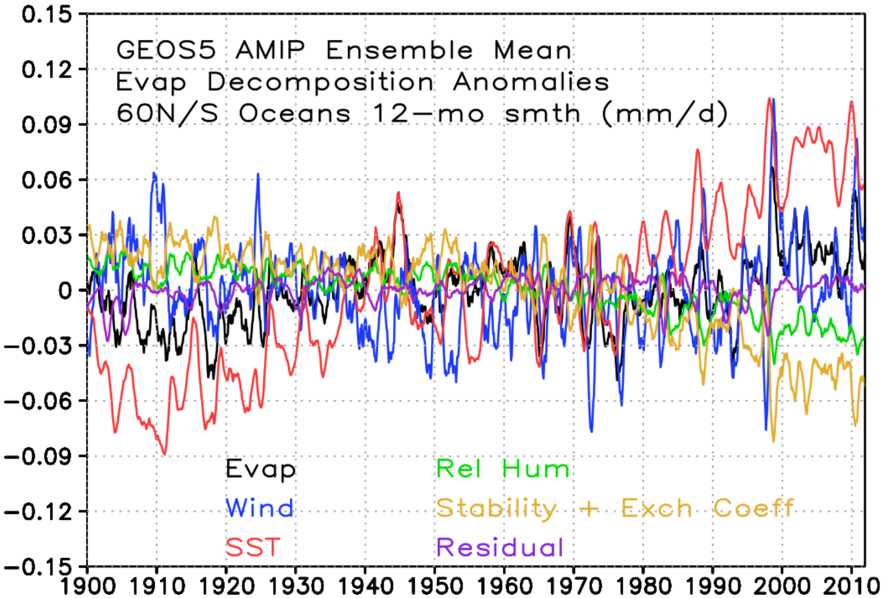
Evaporation anomalies, δE, are expressed as

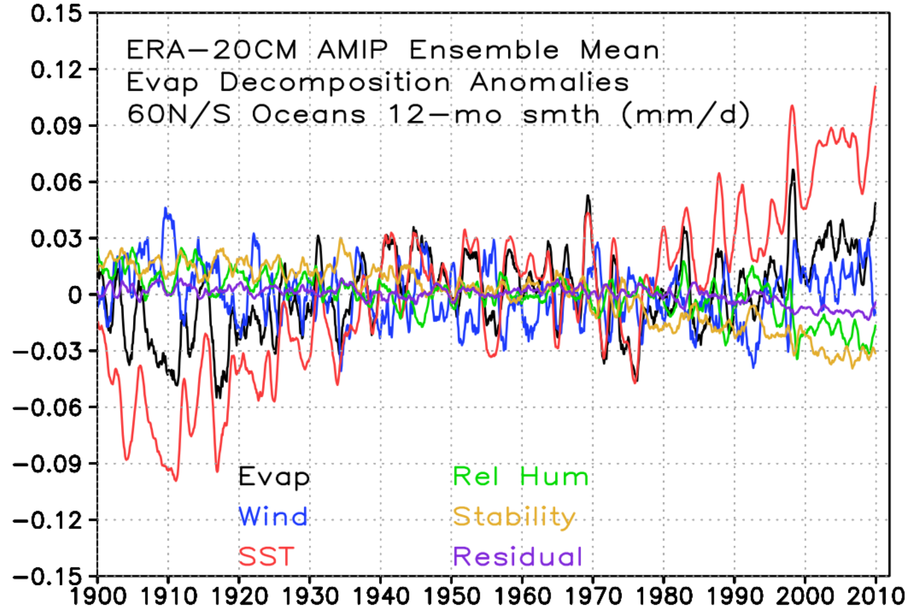
$$\delta E = \frac{\partial E}{\partial SST}\delta SST + \frac{\partial E}{\partial U}\delta U + \frac{\partial E}{\partial RH}\delta RH + \frac{\partial E}{\partial S}\delta S + \frac{\partial E}{\partial C_E}\delta C_E + res$$

where he partial derivatives are “sensitivities” built from monthly resolved climatology and δ( ) denotes a monthly anomaly.

Evaporation Change Mechanisms (AMIP Ensembles)

Ocean 60 N/S time series (mm/d)   12 mon smoothing





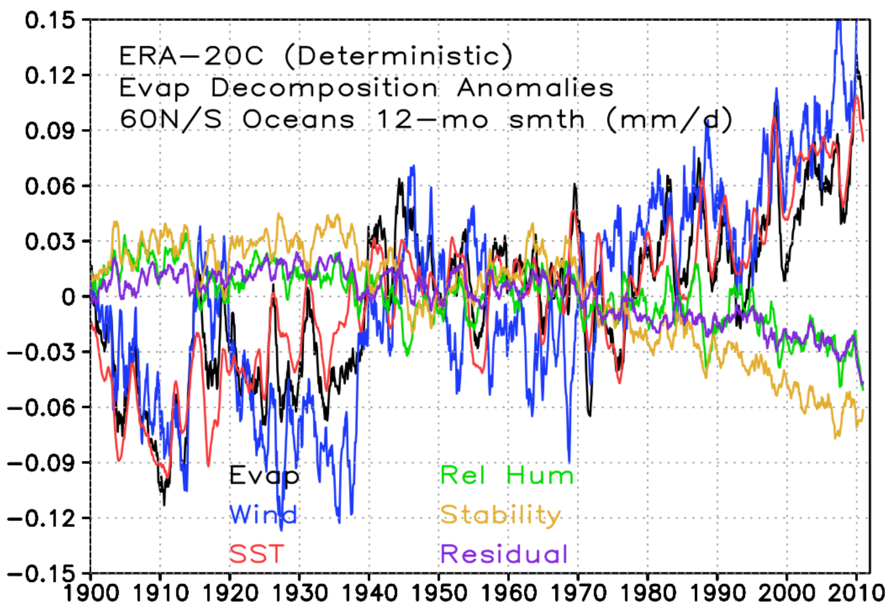
20th Century Trends (% Climo Evap / Deg Global SST Change)

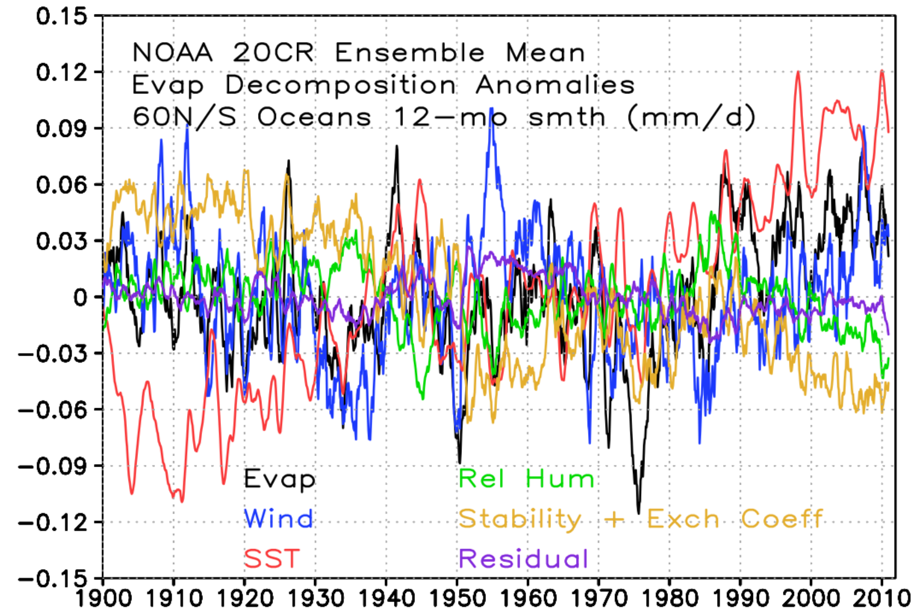
	Evap	SST	RH + Stab + Ex Coeff	Wind	Residual
GEOS5	0.88	5.67	-4.91	-0.09	0.22
ERA-20CM	1.17	5.59	-3.59	-0.50	-0.34

- Actual evaporation trend lies substantially below C-C Rate due to offsetting contributions of increased RH, Stability and Exch Coeff.
- Wind-related trends are small (but interannual signals are large).

Evaporation Change Mechanisms (Reduced Obs Assimilation)

Ocean 60 N/S time series (mm/d)   12 mon smoothing

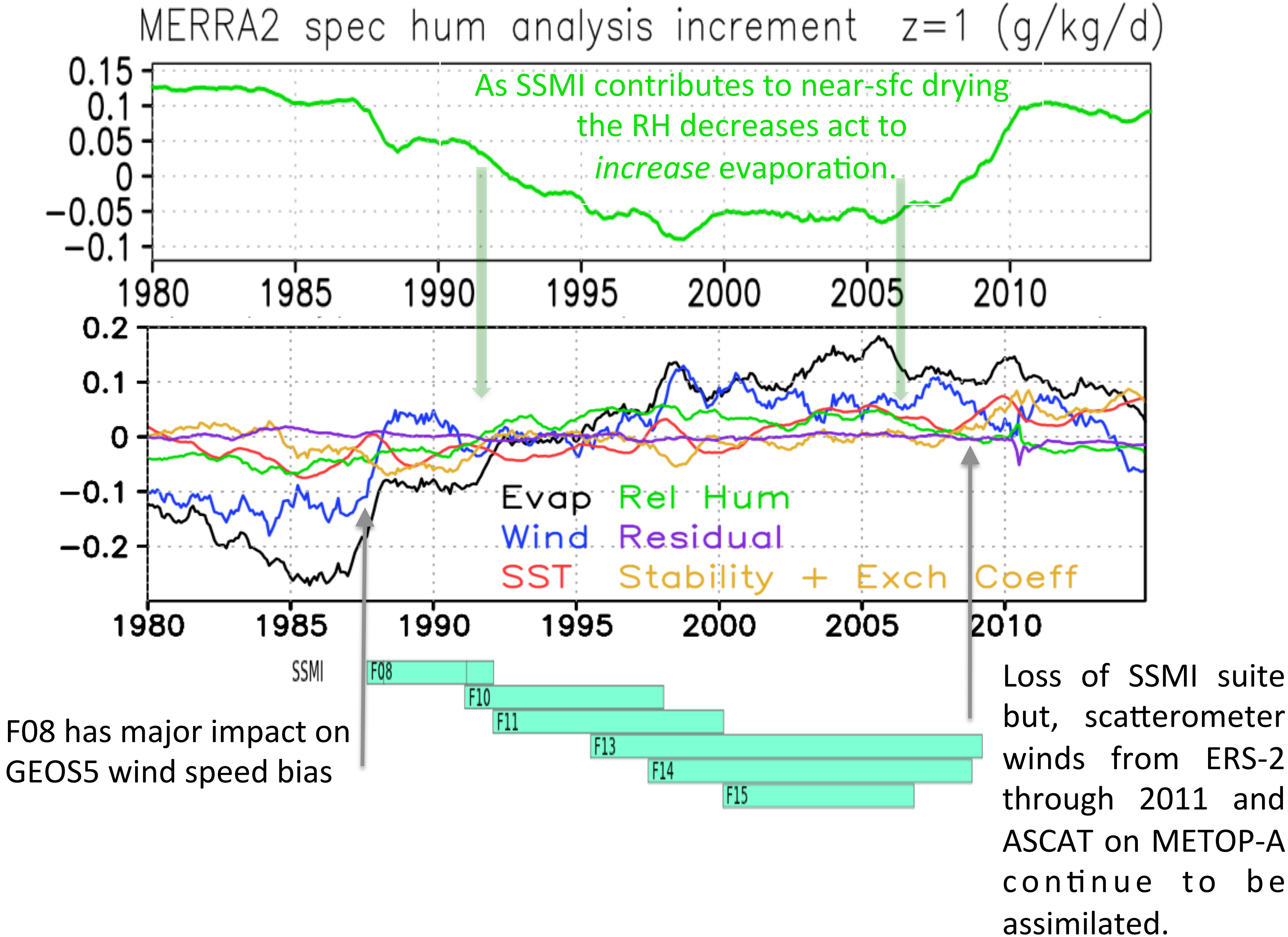




20th Century Trends (% Climo Evap / Deg Global SST Change)

	Evap	SST	RH + Stab	Wind	Residual
NOAA 20CR	0.97	5.67	-4.75	0.24	-.19
ERA-20C	4.95	5.50	-5.56	7.71	-2.70

- Both NOAA 20CR and ERA-20C have more decadal variability than AMIPs
- ERA-20C wind trend drives 20th Century evaporation trend rivaling C-C rate.


MERRA2 spec hum analysis increment z=1 (g/kg/d)
As SSMI contributes to near-sfc drying
the RH decreases act to
increase evaporation.
Evap
Rel Hum
Wind
Residual
SST
Stability + Exch Coeff
SSMI
F08
F10
F11
F13
F14
F15
F08 has major impact on GEOS5 wind speed bias
Loss of SSMI suite but, scatterometer winds from ERS-2 through 2011 and ASCAT on METOP-A continue to be assimilated.

Reduced Observation Assimilation

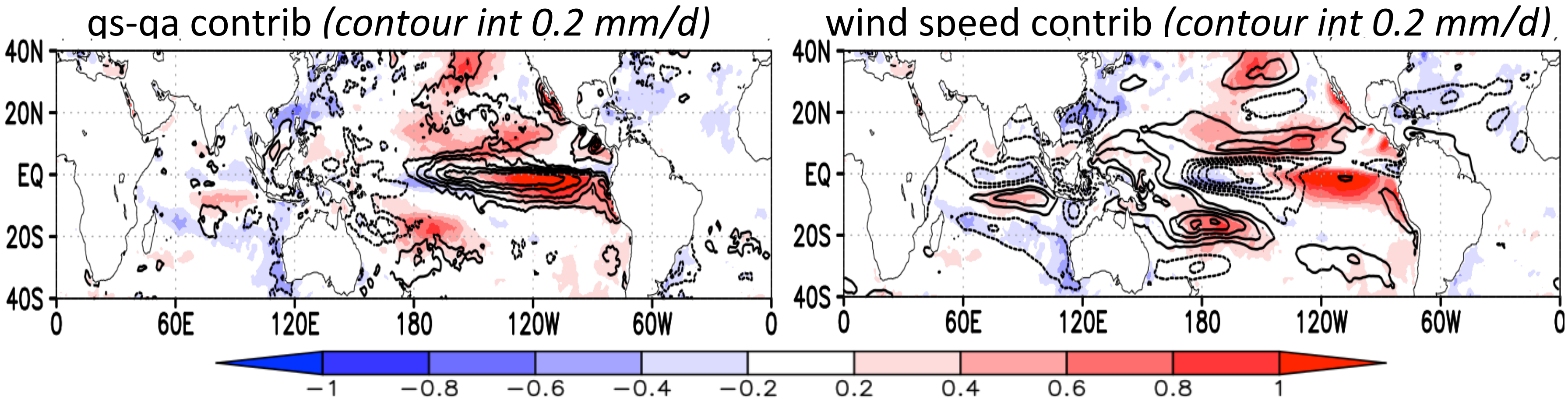
- Assimilating near-sfc weather (P_s and/or wind speed) is a step toward recovery of evaporation (and other fluxes) driven by atmospheric state alone missed by AMIPs.
- **But…** the inhomogeneity of data availability and its quality can induce significant uncertainties.

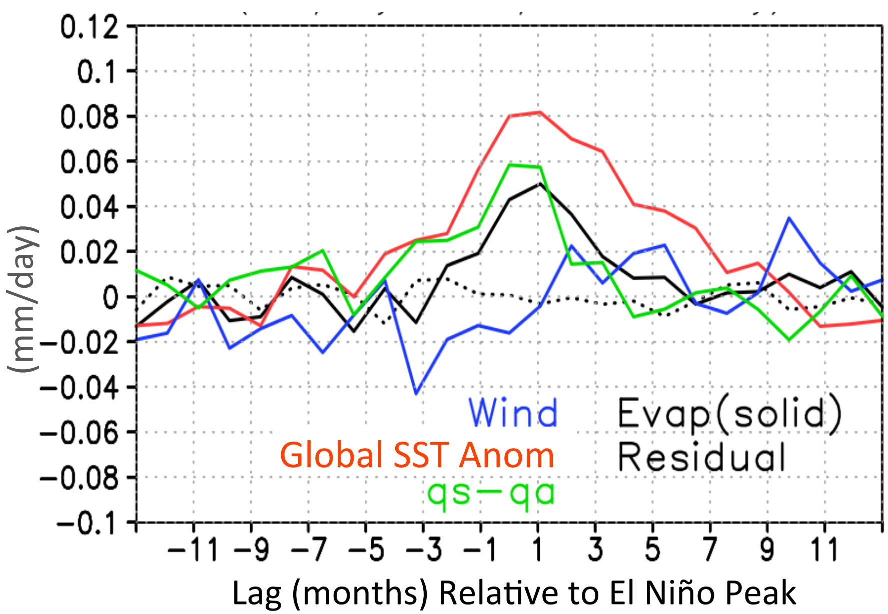
Can we discern physical signals e.g. ENSO, PDO/IPO?

ENSO: hi-pass (<7y) 1950/2010 data & composite by lags relative to Equatorial Pacific SST max

IPO: Epoch difference (1999/2009 minus 1990/1999) fields. Period covers transition from warm to cold IPO phase (~ ”hiatus”)

ERA-20C Composite
El Niño Evaporation Anomalies (shaded, mm/d)





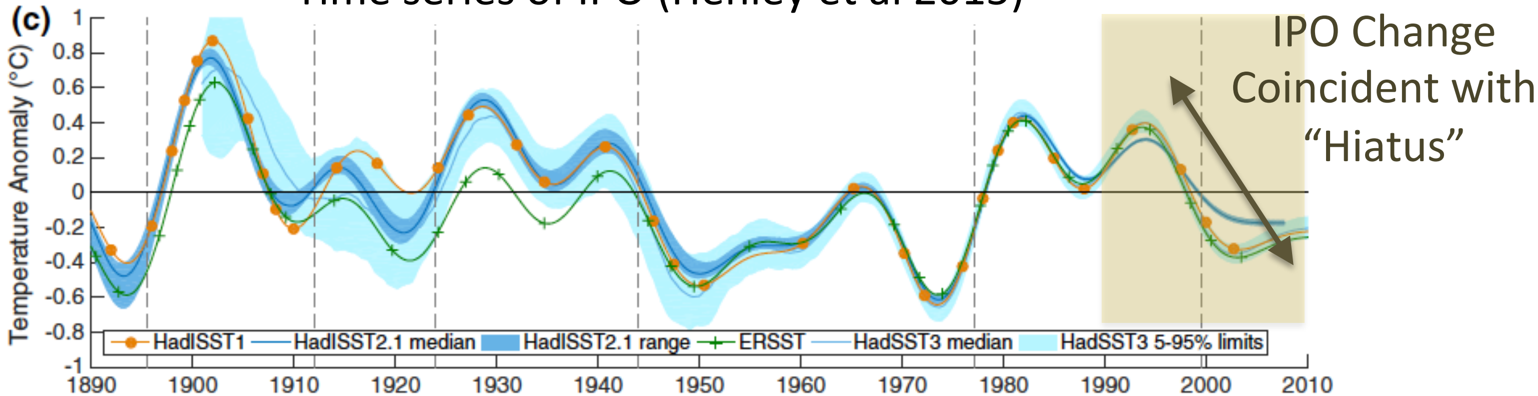
EVAP Contributions: WSPD, QS-QA

1.0σ event composites 1950/2010

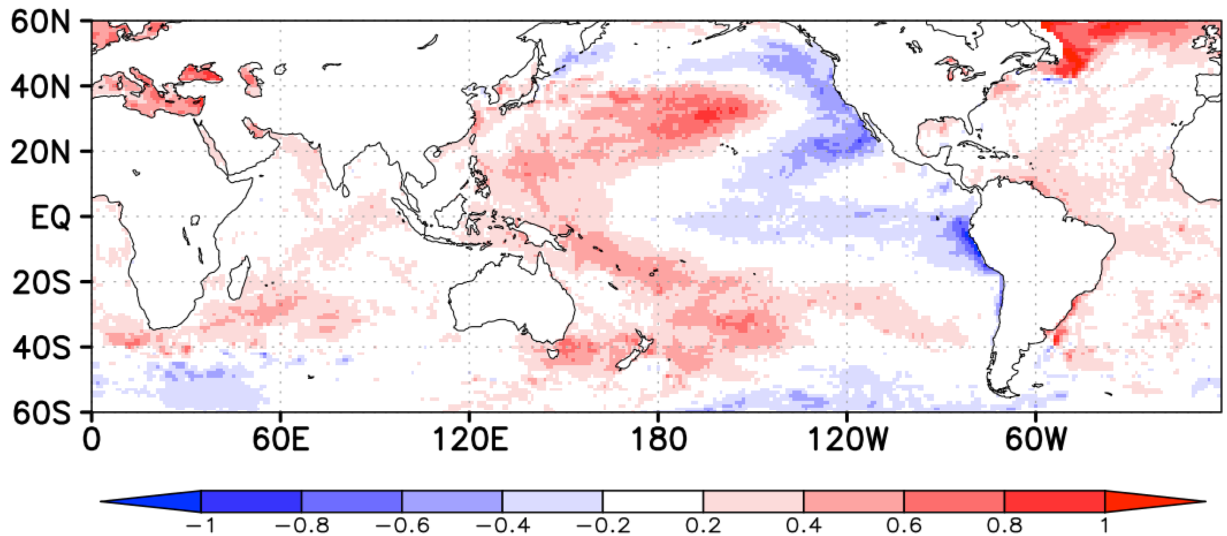
Global Ocean (60 N/S)

Does the Inter-decadal Pacific Oscillation Have a Robust Signal?

Time series of IPO (Henley et al 2015)



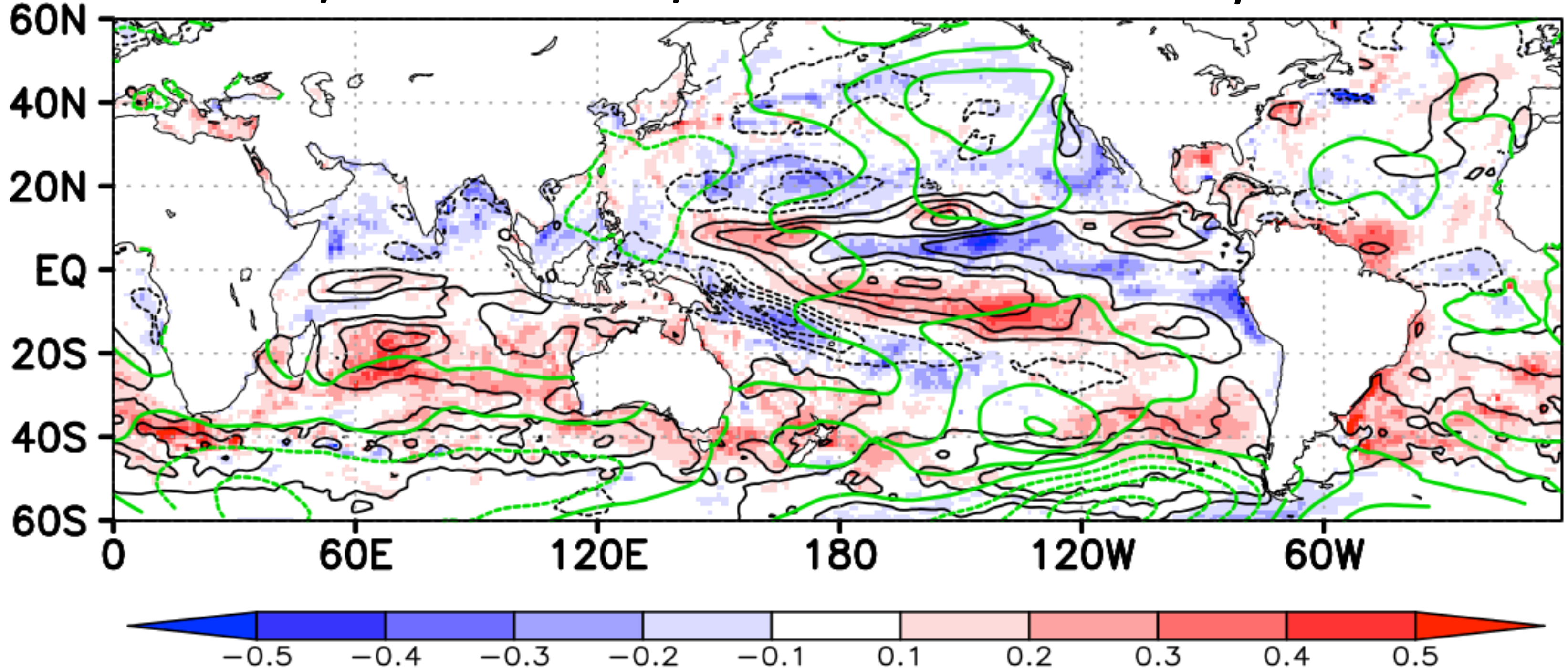
ERA-20C SST (°C) 1999/2009 minus 1990/1999



Inter-decadal Pacific Oscillation In ERA-20C

- Consistent pattern of evaporation changes (shaded) relate to SST gradient patterns and altered low-level circulation.
- Twin anticyclonic high pressure anomalies (green contours) develop in the eastern extra-tropical Pacific resulting from westward diabatic heating shift.
- Off-equatorial wind speeds Eq to 20 N/S (black contours) consistent with surface pressure gradient changes enhance evaporation.

1999/2009 minus 1990 /1999 *Transition to IPO cold phase*



Summary Points:

- Consistent with coupled model results (e.g. Richter and Xie, 2008; Lorenz et al, 2010), process related diagnostics indicate AMIP experiments show thermodynamic damping by RH and stability act to keep evaporation trends below C-C rate.

- Reduced Observations Reanalyses (RedObs) assimilating surface pressure (and wind) can provide a more consistent picture of evaporation variability. Some issues: wind speed shift @1940; dearth of So. Hem. observations.

- El Nino-related IA evap variations are large regionally. Equatorial wind speed decreases lead qs-qa maximum → evap max tends to lag Eq SST max → coherent global signals.

Challenges:

- Data scrubbing / refurbishment a continuing need. Cross-comparisons among "hierarchy" products with varied data input are useful in ferreting out uncertainties.

- Significant changes in data availability in the Satellite Era continue to challenge comprehensive reanalyses. More attention to reanalysis model analysis increments is needed to understand data / physics bias interplay.

- Future versions of satellite evaporation retrievals will likely have reduced trends due to better sensor calibration effects on wind speeds. Qs-qa biases need further study. Wx "regime" approaches a way forward.

Thanks!